Cadaveric Scapholunate Reconstruction Using the Ligament Augmentation and Reconstruction System

Kevin Eng, FRACS[1] Michael Wagels, FRACS[2,3] Stephen K. Tham, FRACS[2,3,4]

[1] Department of Orthopaedics, Barwon Orthopaedic Research Unit, The Geelong Hospital, Geelong, Victoria, Australia
[2] Victorian Hand Surgery Associates, Fitzroy, Victoria, Australia
[3] St. Vincent's Hand Surgery Unit and Hand and Wrist Biomechanics Laboratory, O'Brien Institute, St. Vincent's Hospital, Fitzroy, Victoria, Australia
[4] Department of Orthopaedic Surgery, Dandenong Hospital, Dandenong, Australia

Address for correspondence Stephen Tham, FRACS, St Vincent's Hand Surgery Unit and Hand and Wrist Biomechanics Laboratory, O'Brien Institute, St. Vincent's Hospital, Fitzroy, Victoria, Australia (e-mail: stham@bigpond.net.au).

J Wrist Surg 2014;3:192–197.

Abstract

Background Untreated scapholunate ligament disruption may lead to progressive wrist arthritis. Current techniques used to treat the disruption may not prevent arthritis because of attenuation of a reconstructive ligament substitute or failure to re-establish normal wrist kinematics.

Questions/Purposes This study evaluates a combined synthetic-autologous technique for the treatment of scapholunate dissociation.

Methods Scapholunate dissociation was created in six cadaveric wrists. The dorsal and volar components of the scapholunate ligament were reconstructed using the Ligament Augmentation & Reconstruction System (LARS; LARS, Arc-sur-Tille, France) and a modified Blatt capsulodesis performed. Reconstructed wrists were subjected to cyclic passive motion. Outcomes were measured radiologically and compared using Student's *t*-test.

Results Carpal alignment was re-established following scapholunate ligament reconstruction. Carpal alignment was maintained after cyclic loading.

Conclusions The technique described corrected the carpal malalignment associated with scapholunate dissociation. Corrected positions were maintained after one thousand cycles of flexion and extension without fraying or loosening of the LARS.

Clinical Relevance Current popular techniques for scapholunate reconstruction do not address the important dorsal and palmar components of the ligament that control their intercarpal motion. Reconstruction of the dorsal and palmar components of the scapholunate ligament can be achieved through a dorsal approach to the wrist.

Keywords
- scapholunate
- reconstruction
- ligament
- LARS

Untreated scapholunate dissociation (SLD) can progress to a scapholunate advanced collapse (SLAC) pattern of arthritis.[1,2] A treatment algorithm was proposed by Garcia-Elias,[3] but there is no universally accepted technique for the reconstruction of irreparable but reducible SLD in the absence of degenerative arthritis. The goal of scapholunate reconstruction is to reestablish and maintain normal radiocarpal and intercarpal relationships but also to restore normal carpal kinematics. Altered kinematics cause progressive arthritis associated with chronic SLD. Ideally this should be achieved

DOI http://dx.doi.org/10.1055/s-0034-1384743.
ISSN 2163-3916.

by correction of rotatory scaphoid subluxation, restoration of the primary and secondary stabilizers, correction of lunate extension, and restoration of carpal height. Current reconstructive options include capsulodesis, bone-ligament-bone graft, tenodesis, and limited wrist fusion. Many of these are able to reestablish normal static carpal relationships but fail to maintain them through carpal motion or under load.[4–6] Despite our knowledge of the primary and secondary stabilizers that must be injured to result in a static SLD,[7] a tissue-specific approach to reconstruction of these stabilizers is not common, and contemporary reconstructions do not restore ligamentous anatomy.

We report an experimental reconstruction for static SLD that reconstitutes both the dorsal and palmar components of the scapholunate interosseous ligament (SLIL) along with a dorsal capsulodesis using a synthetic device, the Ligament Augmentation & Reconstruction System (LARS; LARS, Arc-sur-Tille, France). The purpose of this study is to determine whether this technique can restore carpal alignment in a cadaver model for SLD and whether the reconstruction can maintain scapholunate alignment after cyclical loading.

Materials and Methods

A cadaveric study was undertaken using six fresh-frozen upper limbs disarticulated at the elbow. Posteroanterior (PA), lateral, and oblique wrist radiographs were taken of each specimen to exclude pre-existing wrist pathology. Each specimen was kept frozen until use. All specimens were subject to the same protocol.

A dorsal approach was performed through the fourth extensor compartment. The wrist joint was exposed via a ligament-sparing incision between the dorsal intercarpal (DICL) and dorsal radiocarpal ligaments.[8] The DICL was then released from its insertions onto the scaphoid, trapezium, and trapezoid. The SLIL was inspected and, along with the radioscaphocapitate (RSC) and palmar scaphotrapeziotrapezoidal (STT) ligaments, divided to produce a static SLD with a dorsal intercalated segment instability (DISI) deformity (►Fig. 1b). The degree of dissociation was measured in a repeat wrist radiograph series (►Fig. 2b).

A 3-mm diameter LARS was developed by the manufacturer specifically for this study (►Fig. 3). Tunnels for the transosseous and transarticular passage of the LARS were created using a 3-mm drill entering from the dorsal extra-articular surfaces of the scaphoid and lunate at their capsuloligamentous insertion and directed obliquely and palmarwards to the volar corner of the scapholunate articulation (►Fig. 4a,b). The exit drill holes between the scaphoid and lunate were collinear, and their location was determined by direct visualization after reducing the scapholunate joint. From the dorsal approach alone, the tapered end of the LARS was passed from the dorsal drill hole of the lunate to its palmar exit drill hole and then through the scaphoid from palmar to dorsal drill holes. It was then passed through the closed loop.

The dorsal tilt of the lunate was corrected by placing a transradial lunate pin with the wrist flexed. The wrist was then extended to reduce the dorsally subluxed proximal pole of the scaphoid and to correct the radioscaphoid angle.

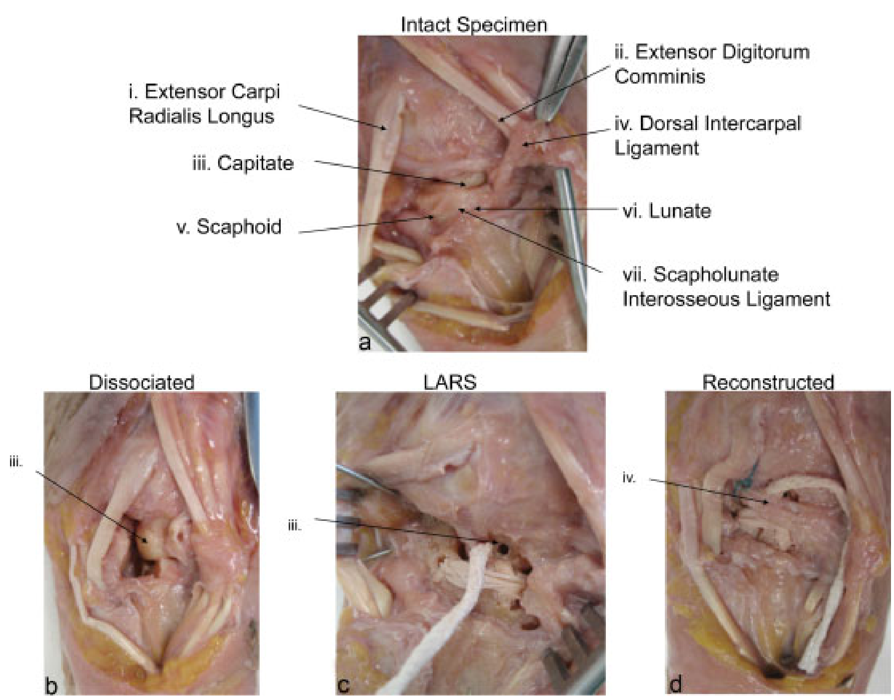

Fig. 1 **(a)** The intact specimen demonstrating the capsule-preserving approach to the wrist joint. **(b)** The dissociated specimen demonstrating ligament release and widening of the scapholunate gap. **(c)** The reconstructed specimen demonstrating the LARS in situ and a drill hole in the dorsal capitate in preparation for fixation with biotenodesis screw. **(d)** The completed reconstruction with the DICL secured to the distal pole of the scaphoid with a bone anchor.

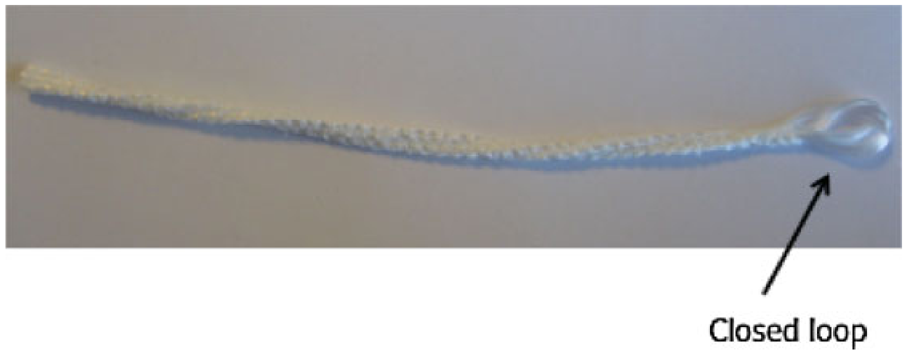

Fig. 2 The LARS that was manufactured specifically for the study.

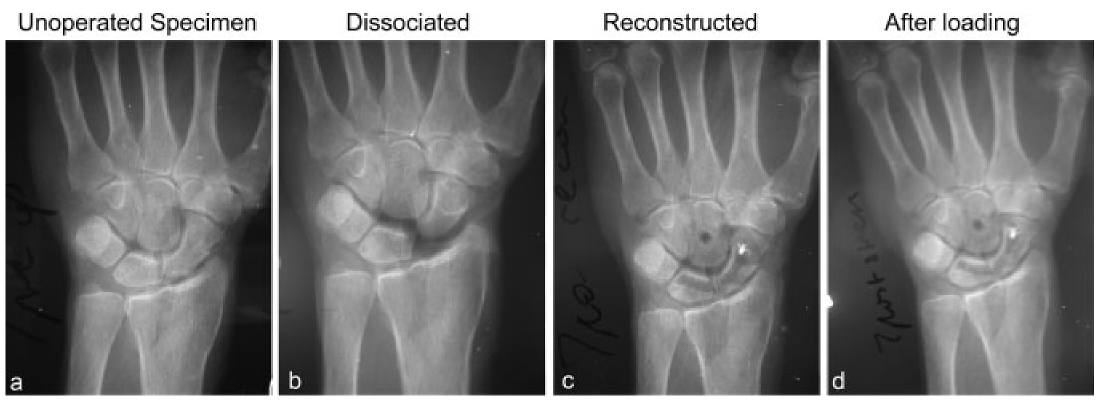

Fig. 3 (a) PA radiograph of the unoperated specimen demonstrating the absence of pre-existing wrist pathology. **(b)** PA radiograph of the dissociated specimen demonstrating a widened scapholunate gap, loss of parallelism, extended lunate and scaphoid ring sign. **(c)** PA radiograph of the reconstructed specimen showing correction of the carpal malalignment noted in ►**Fig. 2b** and a lucency in the capitate representing the drill hole for the biotenodesis screw. **(d)** PA radiograph of the reconstructed specimen after cyclic loading showing no change in carpal alignment.

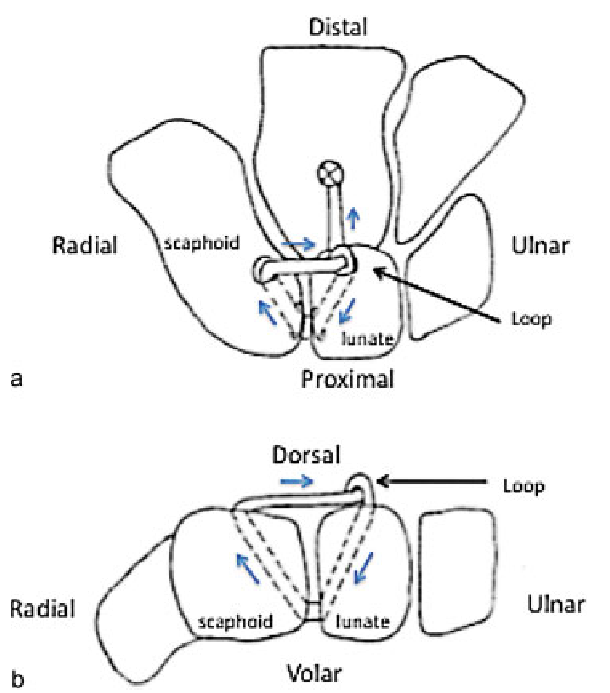

Fig. 4 Line drawing of the ligament reconstruction to demonstrate the course of the intraosseous tunnels and the passage of LARS. **(a)** Coronal view of the right wrist from a dorsal perspective. **(b)** Axial view of a right wrist looking from proximal to distal.

Pronation of the scaphoid was corrected as the dorsally subluxed scaphoid was reduced and the scapholunate interval closed by a bone reduction clamp. There was no requirement for guide wires. The position of the reduced scaphoid was maintained with scapholunate and scaphocapitate Kirschner wires (K-wires) and checked by fluoroscopy. The LARS was then tensioned by hand and its free end fixed by a 4-mm bioabsorbable interference fit screw (Device Technologies, Melbourne) to the dorsal capitate (►**Fig. 1c**). The interference screw kit allows maintenance of tension while screw is inserted. The dorsal capitate was chosen as the fixation point for the free end of the LARS because it is not possible to transfix the LARS to either the lunate or the scaphoid while maintaining tension.

All of the K-wires were then removed. The free end of the DICL, previously released from the scaphoid and the adjacent distal carpal row to effect static instability of the scapholunate articulation, was secured to the distal pole of the scaphoid by a mini bone anchor and 3/0 nonabsorbable suture, a technique established by Rehak et al in 1994.[9] This Szabo modification of the Blatt procedure was performed to prevent excessive flexion of the scaphoid.[10] The skin was closed using a continuous nylon suture and a wrist radiograph series repeated. The operated cadaver wrists were then subjected to one thousand cycles of continuous passive motion from 45

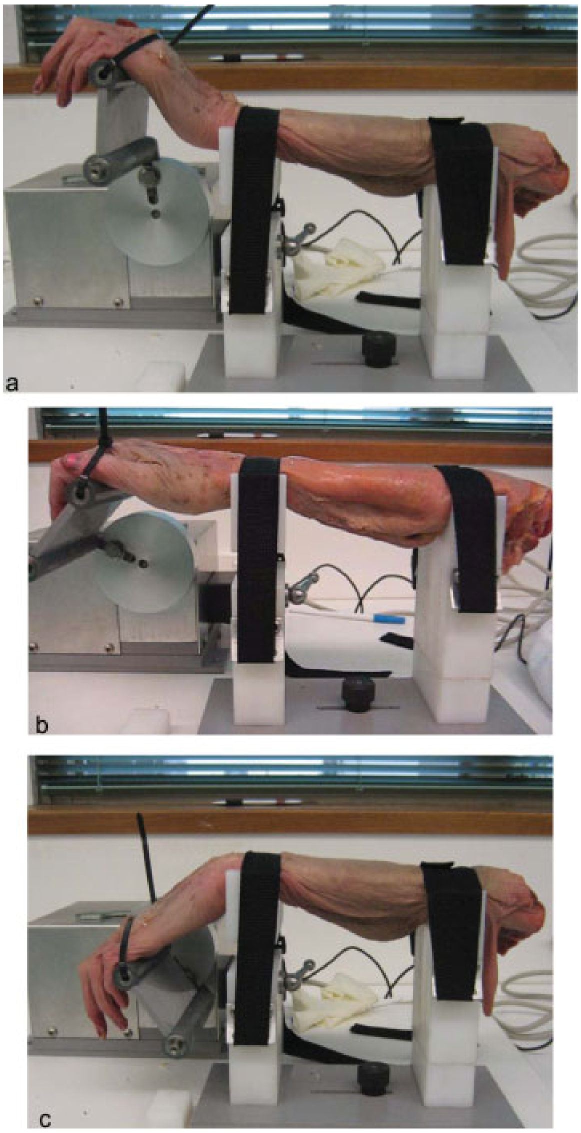

Fig. 5 The purpose-built continuous passive motion machine. **(a)** 45 degrees of extension. **(b)** Neutral. **(c)** 45 degrees of flexion.

degrees of flexion to 45 degrees of extension in a purpose-built electric motorized machine (►**Fig. 5a–c**). The sutured skin was then reopened to allow direct assessment of the reconstruction for loss of position, carpal bone fracture, and fraying of LARS. The wrist radiograph series was repeated for a fourth time (►**Fig. 3d**).

In each series of wrist radiographs, the scapholunate gap, radiolunate, radioscaphoid and scapholunate angles were measured. Measurements were performed using a ruler and a goniometer. Mean measurements were compared using the Student's *t*-test.

Results

Key results are summarized in ►**Table 1**. None of the wrists had pre-existing static scapholunate dissociation or other wrist pathology that was demonstrable either on the radiographs or by direct inspection. The mean unoperated scapholunate gap (SLG) was 0.93 mm. The mean scapholunate (SL), radiolunate (RL), and radioscaphoid (RS) angles before dissociation were 47.8 degrees, –5 degrees of extension, and 41 degrees in flexion, respectively. The mean SLG after ligament sectioning was 5.5 mm. The mean SL, RL and RS angles increased to 78.3 degrees, –9.2 degrees of extension, and 52.5 degrees of flexion respectively.

All measurements after reconstruction were within normal carpal alignment limits.[11] The mean reconstructed SLG was 0.95 mm ($p = 0.18$), and the mean SL angle was restored to 46.5 degrees ($p = 0.33$). The reconstructed mean RL angle (2.17 degrees) was significantly less than the unoperated average ($p = 0.04$). The difference between the unoperated (41 degrees) and reconstructed (37.33 degrees) RS angles was also significant ($p = 0.006$).

Cyclic flexion-extension did not result in statistically significant loss of position. There was no evidence of ligament fraying at the bone–LARS interface, nor were there any bony fractures or loss of position. Two biotenodesis screws fractured during insertion due to inexperience inserting the absorbable

Table 1 Comparison of measured carpal relationships and with normal ranges for angle measurements

Intact Specimen mean (range)		Dissociated mean (range)		Reconstructed mean (range)		Cyclic loading mean (range)		
	A	B	p (A – B)	C	p (A – C)	D	p (C – D)	Norm
SL gap (mm)	0.93 (0.9–1)	**5.5 (4–7)**	**<0.01**	0.95 (0.9–1)	0.18	0.95 (0.9–1)	1	
SL angle	48 ° (35–55)	**78 o (70–85)**	**<0.01**	47 ° (40–52)	0.33	49 ° (41–60)	0.14	51 ° (36–66)
RL angle	-5° -(1–8)	**-9 o -(6–12)**	**0.008**	**-2 °** -(0–4)	**0.04**	-4 ° (3–4)	0.06	-1° (-10–12)
RS angle	41 ° (38–44)	**53 o (50–60)**	**<0.01**	**37 °** (34–42)	**0.006**	37 ° (30–44)	0.7	52 ° (35–65)

Results of significance testing (Student's *t*-test). Significant differences from the unoperated specimens are noted for the dissociated specimens across all indices and the reconstructed specimens across RL and RS angle. The stressed specimens were not significantly different from the reconstructed specimens. Abbreviations: A, intact specimen; B, dissociated specimen; C, reconstructed specimen; D, reconstructed specimen after cyclic loading; Norm, normal range; p(A – B), p-value for the difference between the intact specimen and the dissociated specimen; p(A – C), p-value for the difference between the intact specimen and the reconstructed specimen; p(C – D), p-value for the difference between the reconstructed specimen before and after cyclic loading; RL, radiolunate; SL, scapholunate.

screw at an angle different from that of the drill hole. These were removed and replaced without complication.

Discussion

The treatment of chronic reducible SLD is challenging. There is no universally accepted method of reconstruction. The limitations experienced in reconstructions of the dorsal component in isolation suggest that both dorsal and volar components of the SLIL should be addressed in the ideal reconstruction.[12,13]

The normal kinematics of scaphoid and lunate involve some degree of independent motion. The scaphoid flexes more than the lunate by 19 degrees in 60 degrees of wrist flexion and extends 13 degrees more in 60 degrees of wrist extension.[14] The reconstruction method in this study may not allow independent movements of the scaphoid and lunate, and hence does not restore normal kinematics, particularly because the relatively inelastic LARS has biomechanical properties that differ from an intact SLIL. However, reconstruction of both the palmar and dorsal components of the SLIL may be permissive of small amounts of independent movement, depending on the tension in the repair. In this construct, a torsional force at the scapholunate interval will be transferred into a compressive stabilizing force where reconstructing a single limb of the SLIL would result in shear.

The SLIL has biomechanical properties that are different from those of autologous tissues used to reconstruct it, though those may seem grossly similar. In 1990, Kuhlmann and associates defined the biomechanical properties of the fibrous structures of the wrist. The SLIL had a modulus of elasticity that was lower than those of tendon, aponeurosis, retinaculum, and capsular wrist ligaments.[15] The yield strengths of the dorsal and volar components of the SLIL have been measured at 260N and 117N respectively.[15,16] These differences are compounded by the effect of immobilization and rehabilitation on remodeling of the reconstructive tissues.[17] It is possible that, although it restores the anatomy, a SLAC wrist may still occur, and perhaps an alternate prosthesis or tissue-engineered substitute[18] with properties that more closely represent an intact SLIL may be more appropriate in a clinical setting.

The use of the LARS ligament in this model of SL reconstruction is a study in the use of a ligament substitute and to eliminate the variables associated with using a tendon for reconstruction. LARS is a synthetic braided polyester (terresuisse–polyethylene terephthalate) ligament replacement device. LARS used for patella tendon reconstruction has a yield strength of up to 1500 N and is relatively inelastic, with elongation of 9.6%, though this increases after fibrous ingrowth (16.4%).[19] It is purported to have a lower risk of reactive synovitis than other synthetic ligament reconstructions because fibrous tissue ingrowth provides a viscoelastic layer between fibers, minimizing interfiber abrasion, which has been implicated in fiber particle–induced synovitis and failure in other artificial ligaments.[20] It has been in clinical use for over 15 years, most commonly for anterior cruciate ligament reconstruction in the knee.[21,22]

LARS has not been used in the wrist to date. There are, however, concerns about the amount of fibrous tissue ingrowth, ligament wear, slippage from the bone tunnels, and partial tearing of the artificial ligament, which lead to a significant decrease in ultimate tensile strength.[23]

Secondary stabilizers play a role in static SLD. Isolated sectioning of the SLIL leads to a change in scaphoid and lunate motion, but not static SLD.[7,14] Ligaments that have been implicated as secondary stabilizers of the scaphoid include the STT, RSC, DIC, and dorsal radio carpal ligament.[7] Which of these ligaments, alone or in combination, are most important in restoring carpal stability is not known. Nevertheless, it seems clear that some effort to replace the function of these ligaments should be attempted in managing static SLD. The volar extrinsic ligaments are not directly addressed using our repair method. Neither the STT ligament nor the RSC ligaments were reconstructed, though they may potentially be damaged in more severe injuries, which would contribute to rotatory subluxation of the scaphoid.

There are limitations to this study. The testing of wrists in flexion and extension is not physiological. The dart thrower's motion places more emphasis on midcarpal motion and relative sparing of the proximal intercarpal motion.[24] Though flexion-extension is not a physiological arc of motion, it may be a better test of a scapholunate reconstruction. Also, 1,000 cycles is a relatively small number. Though fraying of the LARS was not observed, it may occur at higher repetitions, particularly around bony tunnel edges. In a clinical scenario, burring of the edges may minimize this potential problem but may increase the risk of fracture. Also, the incidence of avascular necrosis, synovitis, and loss of active range of motion could not be measured in this study.

Using this technique, the scapholunate gap was reduced and flexion of the scaphoid and extension of the lunate were corrected. The significant change in the RL and RS angles implies some overcorrection, which may be the result of the dorsal capsulodesis. The technique that is presented is a combined synthetic–autogenous reconstruction designed to address some of the deficiencies of contemporary methods of SLIL reconstruction. Further study will be necessary to determine whether these preliminary encouraging results can be maintained in the clinical situation.

Acknowledgments
We thank Ian Bouch of the Anatomy Department at Melbourne University and Peter Domillo of the Monash University Department of Biological Sciences for assistance organizing specimen dissection, Ian Tew of Zimmer for making cadavers available, Julie Knowlan of Phillips for providing the C-arm for X-ray imaging, Heith Priestly of Device Technologies for providing the biotenodesis screws and mini-Mitek anchors, Diana Bosak-Smith of Corin Australia for assistance in arranging manufacture and supply of the LARS device, and the Victorian Orthopaedic Research Trust.

The study was approved by our institutional ethical review board, Monash University.

This work was performed at the Department of Anatomy, Melbourne University and the Victorian Hand Surgery Associates, Fitzroy.

Conflict of Interest
None

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